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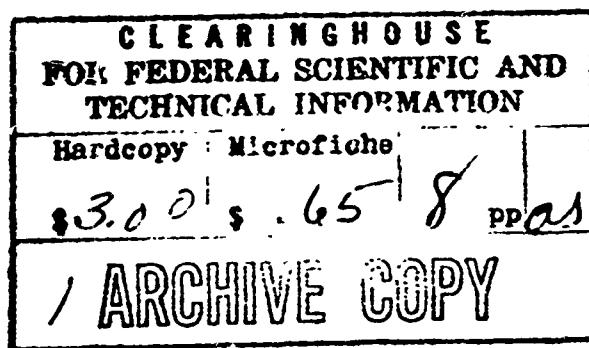
An Annotated Bibliography of Recent Papers
and Reports on the Subject of
Ambient Temperature Aqueous Stress-Corrosion
Cracking of Titanium and Titanium Alloys

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ABSTRACT

A listing is presented of sixteen recent papers and reports which deal with stress-corrosion cracking studies of titanium and titanium alloys. The compilation is limited to cracking phenomena in aqueous solutions at or near room temperature. A brief summary of the important aspects of each report is included.

PROBLEM STATUS

Work on this problem is continuing.

AUTHORIZATION

NRL Problem M04-08A
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INTRODUCTION

Because of its relative immunity from extensive corrosion and pitting in aqueous environments, titanium and titanium alloys have often been mistakenly characterized as being not susceptible to the more serious problem of stress-corrosion cracking. Normally a stress-corrosion crack is initiated at a corrosion pit or other notch of sufficient acuity to raise the local stress intensity above a critical level. In tests of titanium alloys using smoothly machined specimens stress raisers such as these are not present and do not develop during the course of the test. Therefore, subsequent stress-corrosion cracking does not occur.

During the development of a new test for investigating the phenomena of stress-corrosion cracking in high-strength alloys at the Naval Research Laboratory, the formation and growth of stress-corrosion cracks were observed in certain titanium alloys when stressed in an aqueous environment. The forming of a stress raiser corrosion pit which was missing in previous stress-corrosion cracking tests of titanium was obviated in this instance by introducing an edge-notch fatigue-sharpened precrack in a simple cantilever beam type specimen configuration. The stress levels at which these cracks were observed to propagate were sufficiently below the "dry" breaking levels to warrant a more extensive and detailed investigation of the stress-corrosion cracking phenomena in titanium alloys.

Several studies of stress-corrosion cracking have been initiated at various laboratories which cover a wide range of titanium alloys in an equally wide range of heat-treated conditions. It is the purpose of this bibliography to list the papers and reports which have been published as a result of these studies and to briefly indicate some of the more important aspects of each study. The compilation is limited to aqueous stress-corrosion cracking of titanium and its alloys at or near room temperature. It does not include papers dealing with stress-corrosion cracking mechanisms in steels even though some of these mechanisms may "carry over" into nonferrous materials. Nor does it include any reference concerning the problem of hot salt cracking in titanium at elevated temperatures.

BIBLIOGRAPHY

1. Brown, B.F., "A New Stress-Corrosion Cracking Test for High Strength Alloys", Materials Research and Standards, Vol. 6, No. 3, March 1966, pp. 129-133

This test method employs a fatigue precracked bar specimen stressed in simple bending as a cantilever beam. The crack propagation is monitored by a dial gage positioned along the arm of the cantilever beam. Stress levels are expressed in terms of fracture mechanics stress intensity values. Tests of a martensitic steel and a Ti-8Al-1Mo-1V specimen show that stress-corrosion cracking occurs when a minimum stress intensity value (K_{Iscc}) is exceeded.

2. Lane, I.R., Jr., Cavallaro, J.L., and Morton, A.G.S., "Fracture Behavior of Titanium in the Marine Environment", U.S. Navy Marine Engineering Laboratory, R&D Phase Report 231/65, July 1965

A spectrum of titanium alloys was evaluated for sensitivity to sea water in the cantilever beam test. Sensitivity was found to be dependent on aluminum content, isomorphous beta stabilizer content, and heat treatment.

3. Ginsberg, F., and Stern, I.L., "Exploratory Approach for Determination of Susceptibility of High Strength Alloys to Environmental Stress Cracking", U.S. Naval Applied Science Laboratory, Lab. Project 9300-1, Tech. Memo 32, July 1965

A modified Kahn tear-test specimen was used to screen high strength-to-weight ratio materials for susceptibility to sea water stress cracking. The energy to start and energy to propagate the fracture as well as maximum load and fracture appearance were used as susceptibility indicators.

4. Macco, J., "Stress Cracking in Sea Water of Machined Butt Welded Ti-721 Alloy Plate", U.S. Naval Applied Science Laboratory, Lab. Project 6377-5, Tech. Memo. 6, March 1966

Machining of the weld flush with the base plate was found to delay stress corrosion cracking, but once the crack initiation stage was passed failure was very rapid. Stress relieving of the weld at 1450°F did not improve the material's resistance to stress cracking.

5. Brown, B.F., Forgeson, B.W., Lennox, Jr., T.J., Lupton, T.C., Newbegin, R.L., Peterson, M.H., Smith, J.A., and Waldron, L.J., "Marine Corrosion Studies (Third Interim Report of Progress)", U.S. Naval Research Laboratory Memorandum Report 1634, July 1965

A spectrum of titanium alloys were tested in the cantilever dead load test configuration in salt water, fresh water, and sea water. Time to failure at various stress intensity levels is plotted and K_{Ix} and K_{Iscc} values are compared to yield strengths. The results of a number of tests of MIG and electron beam welded titanium plates were also reported.

6. Goode, R.J., Huber, R.W., Howe, D.G., Judy, Jr., R.W., Puzak, P.P., Lloyd, K.B., Crooker, T.W., Morey, R.E., Lange, E.A. and Freed, C.N., "Metallurgical Characteristics of High Strength Structural Materials (Ninth Quarterly Report)", U.S. Naval Research Laboratory Report 6405, November 1965
7. Goode, R.J., Huber, R.W., Judy, Jr., R.W., Howe, D.G., Puzak, P.P., Lloyd, K.B., Crooker, T.W., Morey, R.E., Lange, E.A., and Freed, C.N., "Metallurgical Characteristics of High Strength Structural Materials (Tenth Quarterly Report)", U.S. Naval Research Laboratory Report 6454, April 1966

A wide variety of alloy plates and welds were tested in cantilever type loading to determine the degree of stress-corrosion cracking sensitivity. The results are plotted as stress intensity time to failure plots. Further data on stress-corrosion cracking in titanium alloys will appear in the Eleventh Quarterly and subsequent quarterlies in this series.

8. Williams, D.N., Wood, R.A., White, E.L., Boyd, W.K., and Ogden, H.R., "Studies of the Mechanism of Crack Propagation in Salt Water Environments of Candidate Supersonic Transport Alloy Materials", Final Report Battelle Memorial Institute, Contract No. FA-SS-66-1, January 1966

The alloys Ti-8Al-1Mo-1V and Ti-6Al-4V were investigated using cantilever type loading. Stress intensity levels at failure in air and a neutral 3 1/2% NaCl solution were measured at room temperature. Some tests were also run at 32°F and 150°F. A good correlation between crack propagation behavior in salt water and air was noted.

9. Feige, N.G., and Murphy, T., "Fracture Behavior of Titanium Alloys in Aqueous Environment", Titanium Metals Corporation of America, WESTEC Conference, Los Angeles, California, 1966

Attempts are made in this report to define the testing techniques and basic parameters which have been used to detect stress-corrosion cracking in titanium alloys. The effects of oxide film rupture and ion concentration at the tip of the stress-corrosion crack are also considered.

10. Judy, Jr., R.W., Crooker, T.W., Morey, R.E., Lange, E.A., and Goode, R.J., "Low Cycle Fatigue Crack Propagation and Fractographic Investigation of Ti-7Al-2Cb-1Ta and Ti-6Al-4V in Air and in Aqueous Environments", ASM TRANS, June 1966, pp. 195-207

The crack growth rates of two titanium alloys tested in center-notched plate low cycle fatigue tests in air, distilled water, and 3.5% salt water were measured. Electron microscope fractographic examination of the fatigued cracked areas showed a general correlation between the amount of quasi-cleavage fracture mode and the crack growth rate.

11. Beck, T.R., and Blackburn, M.J., "Stress-Corrosion Cracking of Titanium Alloys", Boeing Scientific Research Laboratories Solid State Physics Laboratory Review, July-December 1965

Charpy-notched specimens stressed in tension were tested in a variety of environments and potentials. Ultimate strength is plotted as a function of strain rate and potential. Dislocation arrangements in thin foils of Ti-Al alloys are shown as a function of Al content.

12. "The Stress-Corrosion and Accelerated Crack-Propagation Behavior of Titanium and Titanium Alloys", DMIC Technical Note, February 1966

A summary of information on stress-corrosion cracking and crack propagation behavior of titanium alloys in a variety of environments. The report includes information on hot salt cracking as well as preliminary results of accelerated crack propagation in salt water.

13. Dohogne, C.L., Hall, G.B., Seeley, R.R., "A Study of the Stress-Corrosion Cracking of Titanium Alloys in Sea Water with Emphasis on the Ti-6Al-4V and Ti-8Al-1Mo-1V Alloys", Reactive Metals, Inc. Research Report No. R471, October 1965

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